FAUNAL INFLUENCE ON SOIL MICROFABRICS AND OTHER SOIL PROPERTIES

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ABSTRACT

The influence of animal activity becomes visible by studying thin sections of soil with microscopes. Several specific soil microfabrics (organic laminae, lenticular fabric, lamellar fabric, mesh fabric, cross hatching) that are directly associated with animal activity are recognized. However, more research is needed to understand the role of the fauna and specific animals in the formation of soil fabrics. A restricted number of other micromorphological features (fecal pellets, inorganic pellets, faunal tubules and chambers and mammilated metavughs) identified so far are used only to indicate the presence of faunal activity in soils. Animals may significantly alter the soil characteristics and have an important role in the chemical decomposition of plant residues and the accumulation of nutrients in the biomass. Their excrement, together with organic residues, is essential in the formation of soil aggregates. Faunal turbation facilitates deep rooting, and consequently, higher production of biomass.

RÉSUMÉ

L'influence de l'activité des animaux devient apparente lorsqu'on étudie au microscope des coupes fines du sol. L'auteur reconnaît plusieurs microstructures spécifiques du sol qui sont directement associées avec des activités animales (feuillets organiques, structure lenticulaire, structure lamellaire, structure en maille, double hachure). Toutefois, plus de recherches seront nécessaires pour comprendre le rôle de la faune dans son ensemble et celui d'animaux spécifiques dans la formation des diverses structures des sols. Un nombre limité d'autres traits micromorphologiques qui ont été identifiés (boulettes fécales, boulettes inorganiques, petites galeries et chambres d'animaux, et métavughs mamelonnés) ne sont pour l'instant utilisés que pour indiquer la présence d'activité animale dans les sols. Les animaux peuvent altérer d'une manière significative les caractéristiques des sols et jouent un rôle important dans la décomposition chimique des résidus végétaux et dans l'accumulation des éléments nutritifs dans la biomasse. Leurs excréments, combinés avec les résidus organiques, sont essentiels à la formation des agrégats des sols. Le remuement causé par la faune facilite l'encracinement en profondeur et, par conséquent, favorise la production d'une biomasse plus élevée.

INTRODUCTION

Every soil provides a habitat suitable for animal life. Because of the presence of large quantities of living and dead plant and microbial materials which serve as a continuous food resource, soil animals are generally restricted to the organic or mineral surface horizons. However, animals may also be active at lower depths.

In his early studies, Kubiena (1938) pointed out that the association, activity and structure of soil organisms are primarily controlled by the space condition, microclimate (temperature, moisture, air pressure, insolation, and air movement), pH and salt concentrations, and food conditions in the microhabitat. The heterogeneous nature of soil provides a variety of habitats in which animals can survive and reproduce.

Aquatic forms such as protozoa and nematodes restrict their lives to the moist zone where free or capillary water is available. Apart from these aquatic forms, soil animals are organized into two major groups as suggested by Lee and Wood (1971): (i) animals unable to burrow, and (ii) animals that burrow and reshape the soil. Because of the changes taking place in the soil year-round such as heating, desiccation, freezing of the surface and/or sheltering from predation, members of the second group have the ability to accommodate themselves quickly by moving to a soil zone that meets their requirements. Despite the concentration of biological activity in surface horizons (Bal, 1970; Whittaker, 1974; Bal, 1982), tracks of small soil animals were found down to 150 cm, even in soils of arctic and subarctic regions (Federova and Yarilova, 1972). In semi-arid climatic regions, many animals commonly occur down to 3 m (Kubiena, 1953; Price and Benham, 1977; Valiakhmedov, 1977a,b).

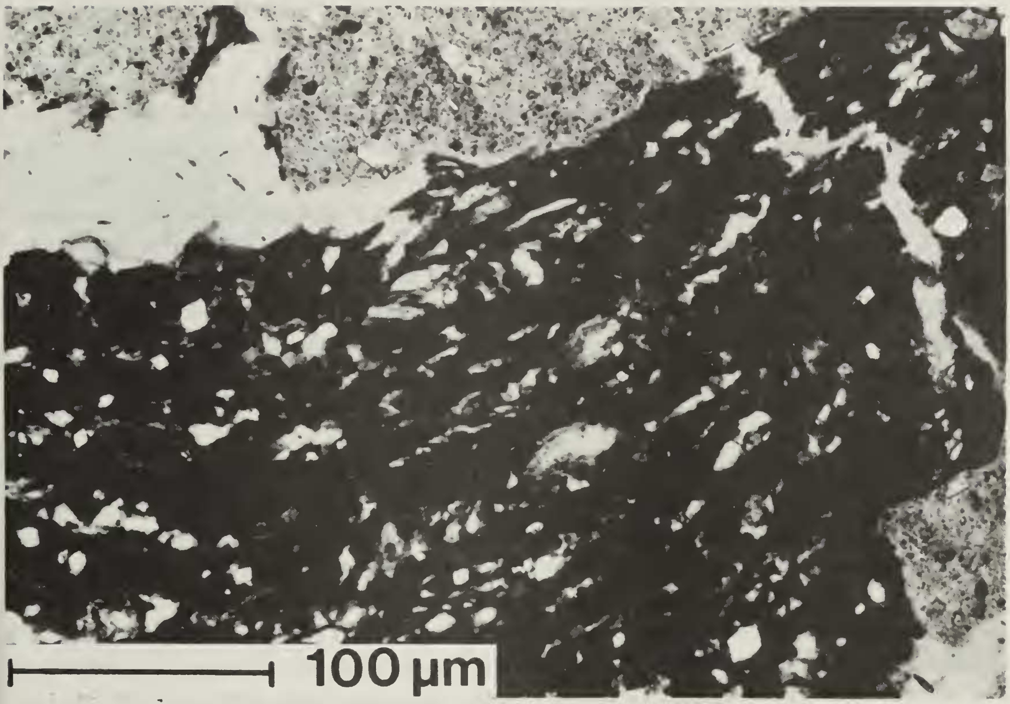
Improvement in preparation techniques for thin sections of soil has made it possible to directly observe and study the influence of biological activity and the role of animals in soil genesis. Much of our present knowledge results from the pioneering studies and efforts of Zachariae (1965, 1967) who described the development of humus forms by specific soil fauna. Attempts were also made, especially in semi-arid and arid regions, to establish the relationship between particular groups of animals and the soil types (Valiakhmedov, 1977a, b; Ghilarov, 1978). Because of the complexities in temperate humid regions, Bal (1982) found great difficulties in the interpretation of the relationship between the soil and its community. The major problem today is the lack of study in the interface between biology and pedology.

Several signs of animal activities are found in thin sections of soil. Excrements are one of the easily recognized features which characterize the nature and the feeding habits of the animals. Structures within the soil body such as chambers, including pupal chambers of soil dwelling invertebrates described by Valiakhmedov (1977a, b) and pedotubules described by Brewer (1976) are other important features that may be used in recognizing and understanding animal activity in soil. As well, studies indicated that a certain part, or even an entire profile, can be partly to completely reworked by animal activities (Buntley and Papendick, 1960; Mulders, 1969; de Meester, 1970; Valiakhmedov, 1977a, b; Bal, 1982). Such mixing processes are referred to as "faunal pedoturbation" (Hole, 1961; Jongerius, 1970).

Despite the efforts made in the past, our present understanding of soil animals and their effects on soil characteristics seems to be far from complete. This paper is aimed only at elaborating on the present level of knowledge on micromorphological features that are formed by animal activity. As an integral part of the interpretation of soil micromorphology, faunal effects on other soil properties are also included in the present report.

FAUNAL INFLUENCE ON SOIL FABRIC

A wide range of soil microfabrics are directly associated with animal activity in soils. However, at this stage there is a need for detailed micromorphological studies to fully understand and recognize the special soil fabrics which are induced by the faunal activities. As an attempt in this direction, the information noted below was summarized from a few available studies dealing with the microstructure of termite mounds (Stoops, 1964; Lee and Wood, 1971, Sleeman and Brewer, 1972 and Mermut *et al.*, 1984). Microfabrics so far recognized in termite mounds (landscape features that are entirely biologically produced) include organic laminae, lenticular fabric, lamellar fabric, cross hatching and mesh fabric, which are considered to reflect the process of construction of the termite nest, and comprise remnants of their activities



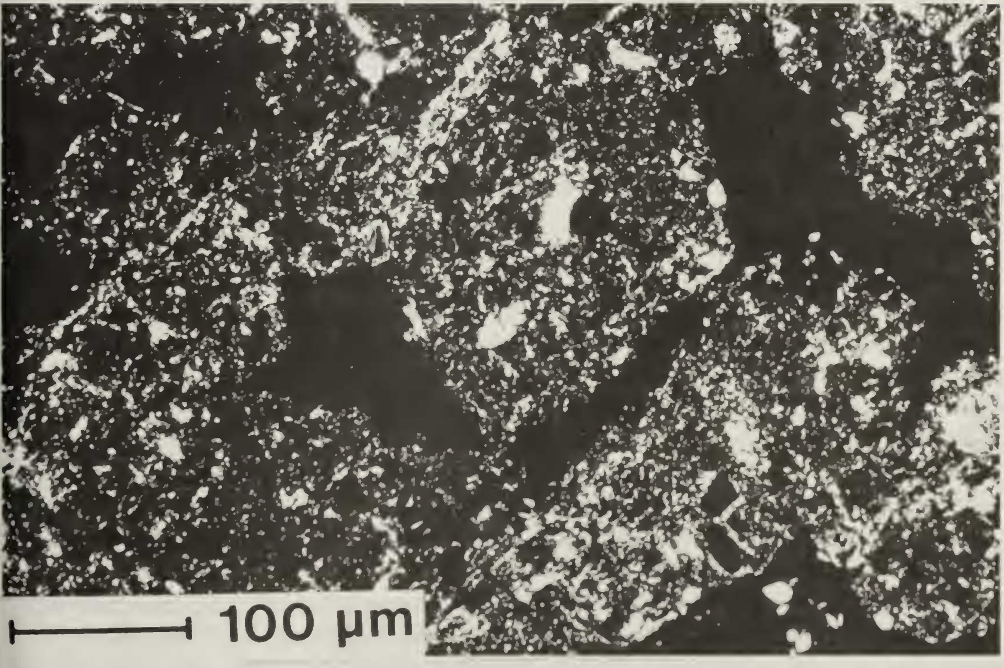


Fig. 1. Organic laminae (dark areas) and lenticular-fabric. *Macrotermes subhyalinus* gallery wall from Kenya (plane light). Fig. 2. Lenticular fabric formed by lenticular units. *Macrotermes subhyalinus* nursery section from Kenya (crossed nicols).

in the soil.

Organic Laminae

These consist of dark reddish brown to black, very weakly and strongly anisotropic material occurring as bands commonly 20μm wide found adjacent to existing gallery walls (Fig. 1) or within gallery fills. Their distinctive color allows an easy recognition and delineation of boundaries with the microscope. Organic laminae may be characteristic for certain termite species. They are richer in organic matter than the surrounding soil material. According to Lee and Wood (1971), they are likely made of excrements with a semiliquid consistency. Organic matter in some of the laminae is more highly humified than in others. More melanization, considered as an indication of increased humification, suggests that this organic material has passed through the gut of the termite.

Lenticular Fabric

The elongated lens-shaped units found in termite mounds were described as lenticular by Stoops (1964). Strong welding of single small lenticular units may develop into a large lenticular unit exceeding 5 mm in size (Mermut *et al.*, 1984). Low content of skeleton grains and high amount of inorganic plasma encourages the formation of larger pellets (Fig. 2). The units consist of dominantly mineral plasma and some pedological features, skeleton grains and little organic matter. Micromorphological observations indicate that each unit consists of different proportions of plasma and skeleton grains. The fabric consists of strongly accommodated lenticular units.

Lamellar Fabric

Fabric consisting of alternate parallel alignments of skeleton grains and plasma in which the parallel arrangement is sometimes associated with planar voids was termed "lamellar structure" by Stoops (1964) and "lamellar fabric" by Sleeman and Brewer (1972). This fabric was found in soils which had high contents of both sand and silt. The skeleton grains are embedded within the soil matrix; the plasma shows extremely well-developed masepic fabric. Because of the parallel arrangement of clay domains, Stoops (1964) termed this fluidal structure. The groundmass of such structures appears to be very dense. Aside from the above-mentioned planar voids, there are no voids visible in such a fabric. The majority of the colors of the groundmass in the lamellar fabrics are similar to the original soil plasma from which the mound was built. However, addition of humic particles may cause the plasma to be somewhat darker in color.

Cross Hatching

This may be considered a subtype of lamellar fabric in which two sets of parallel arrangement of plasma and skeleton grains cross each other (sometimes 90°). The resulting feature is like lattisepic fabric of Brewer (1976), which by definition considered only the arrangement of the clay domains. This type of fabric is found near the gallery surfaces of termite mounds (Mermut *et al.*, 1984) (Fig. 3). Our experience so far indicates that both lamellar and cross-hatching can be considered to result from activity of burrowing animals.

Mesh Fabric

This fabric type results from the specific arrangement of either spheroidal or lenticular construction units. Each construction unit has a separation zone of plasma that can be compared with skelsepic fabric (Brewer, 1976). Welding of individual units in a preferred direction results in a type of plasma orientation resembling a mesh, called "mesh fabric" by Mermut *et al.* (1984). If strong welding occurs in each construction layer, the borders of earlier units appear more diffuse. This type of fabric is attributed to the homogeneity as well as high content of plasma.

OTHER MICROMORPHOLOGICAL FEATURES FORMED BY ANIMAL ACTIVITY

This group includes fecal pellets, pellets built as construction units, faunal tubules and chambers, and mammilated metavughs.

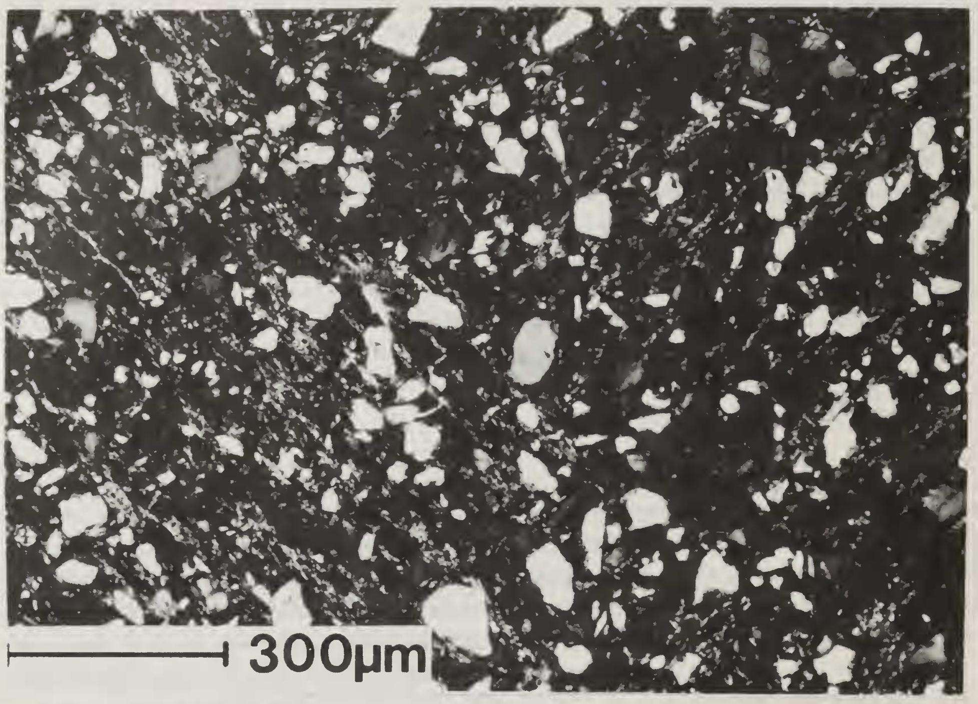
Fecal Pellets

Fecal pellets are the excreta that have left an animal's intestines as shaped, three-dimensional units (Bal, 1973). Recognizable fecal pellets can be seen in a pedotubule, inorganic horizons (Fig. 4), or within large interconnected pore spaces. Unfortunately, little is known about the morphological characteristics of the fecal pellets. Brewer (1976) suggested that a major subdivision of fecal pellets can be based on the external shape. Bal (1973) was able to distinguish five main groups: spherical (Fig. 5), ellipsoidal, cylindrical, platy and threadlike. Bal suggested that one should study and describe the characteristics in the following order of succession: shape, size, composition, basic distribution.

Easily recognizable fecal pellets are found in burrows (Fig. 6), tunnels or chambers, which may extend deep into the profile. Therefore, this feature subjected to the proper recognition can be used as an absolute indication of biological activity. However, as a result of a disturbance of soil material, for example by pedoturbation, the fecal pellets may become embedded in the soil material, and thus become difficult to identify and describe.

Pellets Built as Construction Units

Pellets built as construction units are termed "construction elements" by Stoops (1964). Those units recognized in termite mounds are composed of skeleton grains, plasma, and pedological features. They are spheroidal, ovoid or lens-shaped and vary in size from 125 μm to 1000 μm. Mermut *et al.* (1984) described two distinct types of pellets; one is highly isotropic, light yellowish in color with more clay mineral plasma appearing to be oral pellets mixed with saliva, and the other is brownish, slightly isotropic probably mineral plasma mixed with excreta. According to Arshad (1981), some *Macrotermes* species selectively prefer fine soil separates (particles less than 0.5 mm) to construct their mounds. Lee and Wood (1971) indicated that in a Podzolic soil, the termites preferred to use clay-rich subsoil to encase their mound. Stoops (1964) observed that, during restoration of q mound, the termites piled up the little units of sand and clay, moistened with their saliva. Quick-drying of the outer crust of the pellets creates a plasma separation around each unit, allowing their recognition, even when they are extremely welded. This separation of plasma is comparable to the skelsepic plasmic fabric of Brewer (1976). Except for granular aggregates found in the cracks of the Vertisola which resemble these units, pellets can also be used as a sign of biological activity in non-selfmulching soils. However, the random distribution pattern of the granular aggregates in the swelling clay



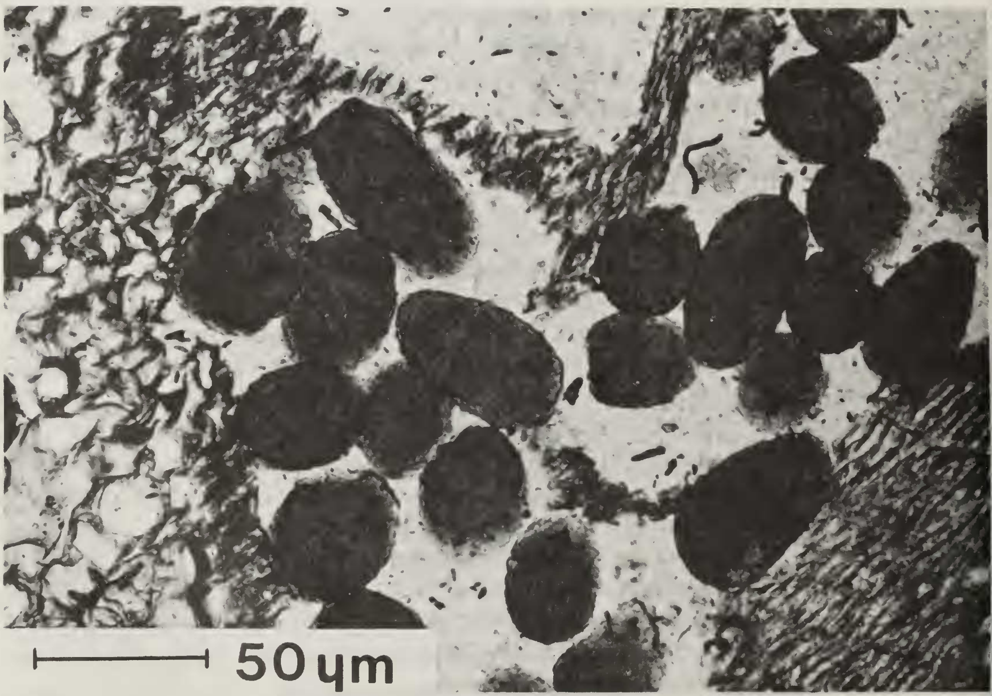
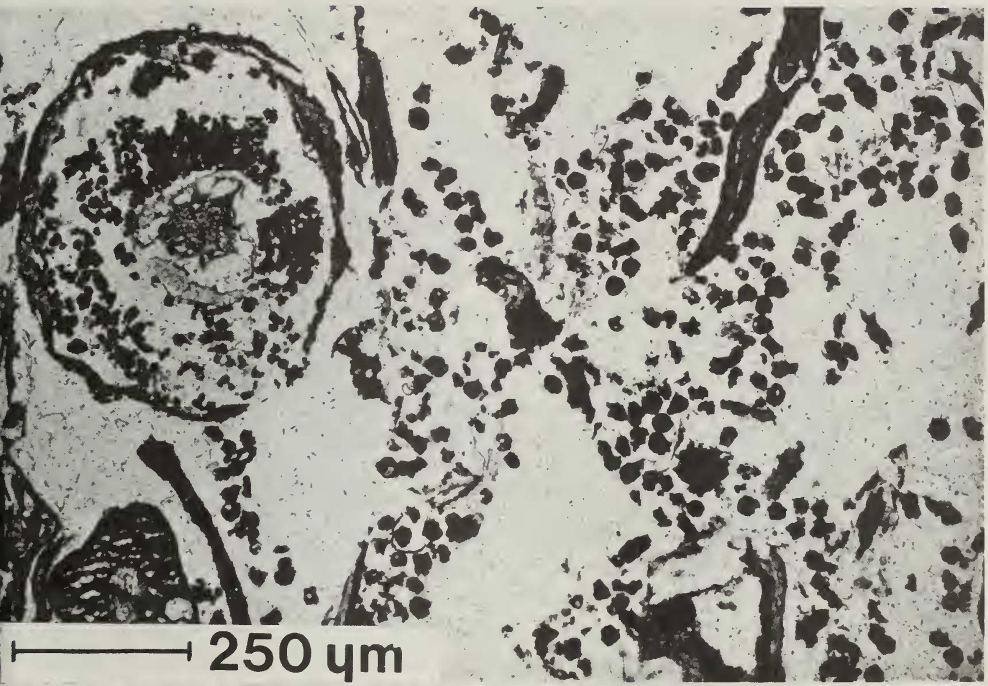


Fig. 3. Cross-hatching observed in a *Macrotermes herus* mound from Kenya (cross nicols). Fig. 4. Single organic ellipsoidal fecal pellets from the organic horizon of a Luvisolic forest soil in Saskatchewan (plane light).



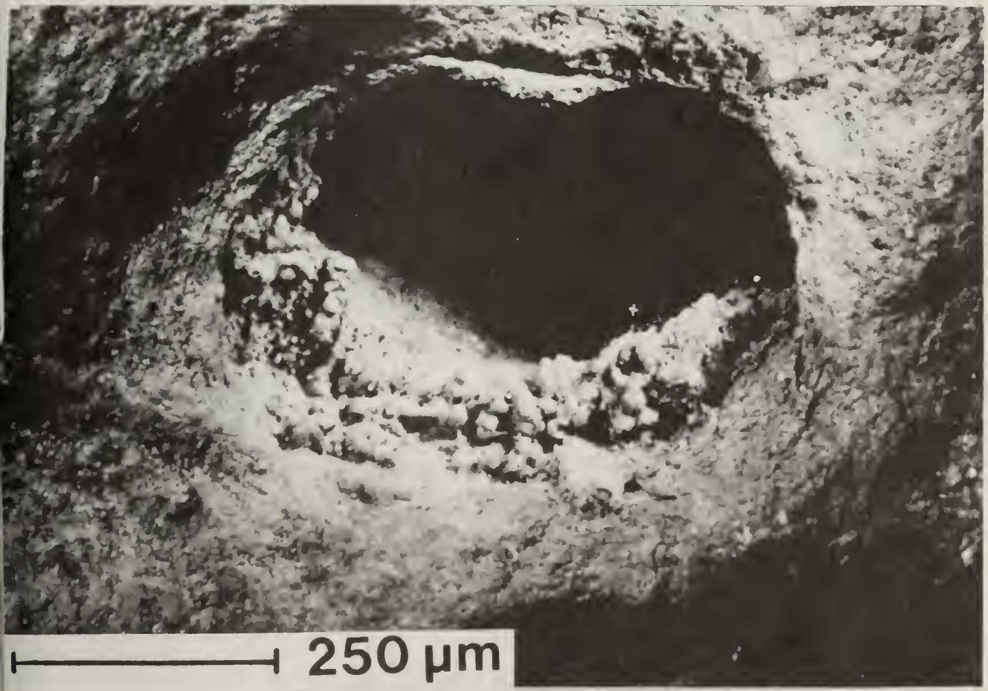


Fig. 5. Single organic spherical melanized fecal pellets from the organic horizon of a Luvisolic forest soil in Saskatchewan (plane light). Fig. 6. Fecal pellets around a zoogenic tube (an African termite burrow), as seen with a binocular microscope.

soils may serve to differentiate the pellets even in these soils.

Faunal Tubules and Chambers

These are features which have sharp external boundaries and are generally larger than the voids in the soils. Faunal tubules have a tubular external form and are made by soil animals that can burrow and reshape the soil materials. Tubular-shaped voids can also be formed by growing roots and may be confused with faunal tubules. Characteristics like wall lining (Bal, 1973) and imprints caused by the bodies of animals may be used to identify zoogenic tubes (Jongerius and Reijmerink, 1963). Excreta in tubules support their origin as faunal burrows.

The burrowing of earthworms is more uniform and generally larger than the tubular-shaped voids produced by growing roots. The voids created by earthworms are the same diameter as their body. However, it is not always possible to use size of the burrow to identify the animals responsible for construction of tubules in the soil. For example, termites and ants make a tubule much larger (Fig. 6) than their bodies; however, we know now that these animals produce special soil fabrics around their burrows.

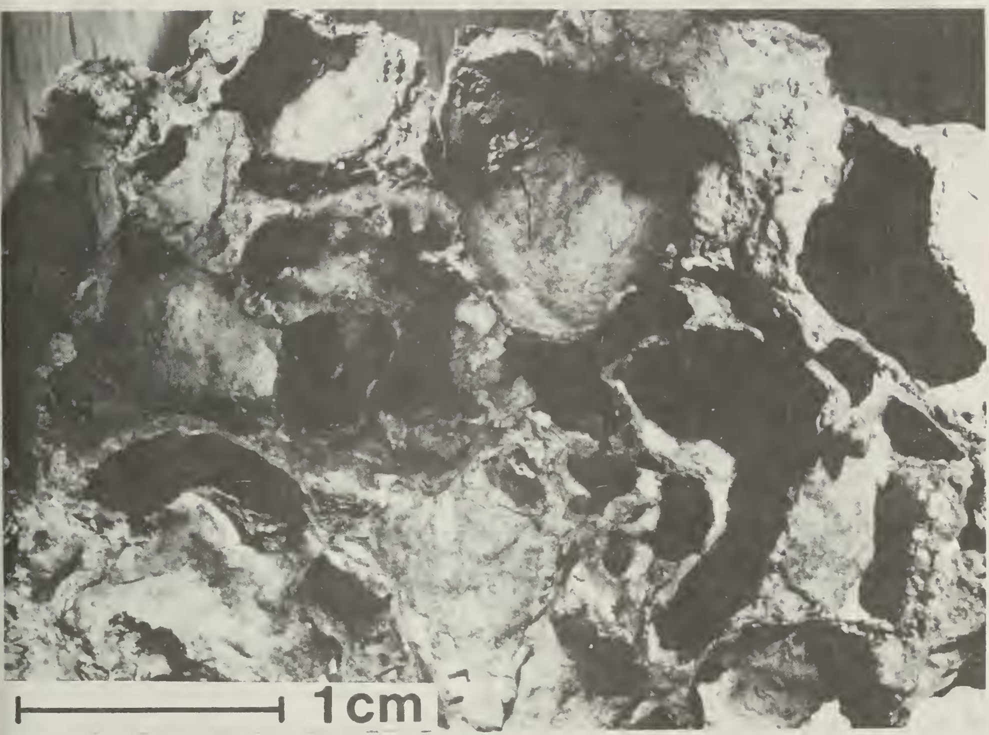
Chambers differ from large voids in soils in that their walls are regular and smoothed (Fig. 7). Their formation has been attributed to faunal activity. In termite nests, chambers have arched or domed roofs and relatively flat floors. As can be clearly seen in Fig. 6, animals (for example, termites) sometimes coat the walls of their tunnels with clay, forming a smooth cutanic feature. Dark staining of gallery walls which is a characteristic found in termite mounds can also be attributable to faunal activity. Surface smoothing, discoloration of burrows, cementing and dense packing and excreta in voids are other characteristics that can be recognized in soil thin sections.

Mammilated Metavughs

As indicated by Brewer (1976), these special vughs have smoothed walls and mammilated conformation. Mermut *et al.* (1984) found this special void in almost all the thin sections from the African termite mounds. Brewer (1976) reports that mammilated vughs occur commonly in soils with strong evidence of extensive faunal activity, especially earthworms. The voids are formed by either welding of pellets used for mound construction (Fig. 8) or faunal excreta. Coalescing fecal pellets and/or pellets used for construction may form empty spaces with sharp protuberances. For pellets used for construction, the plasma reorientation around each unit is clearly observed. Therefore, the soil matrix in contact with the vughs invariabily shows a vosepic plasmic fabric. Mammilated metavughs often bear some additional marks (orderly arrangement of units, darkening of soil material with increased density) which can be used for further evaluations. Many mammilated vughs may serve as good indicators of animal activity in soils.

FABRICS FORMED BY DECOMPOSITION OF ORGANIC MATTER

Soil animals play a very important role in fragmentation of litter and redistribution of organic materials in soil. Excrements of different shape, size, color, orientation, and composition indicate consumption of litter by soil fauna. Some of the animal species, as for example enchytraeids (Zachariae 1964) consume decaying arthropod faeces, pierce and cleave the compact excrement of big earthworms, and eat humus earth as well. Thus, decomposition is a continuous process in which the animals work in close association. All plant residues and



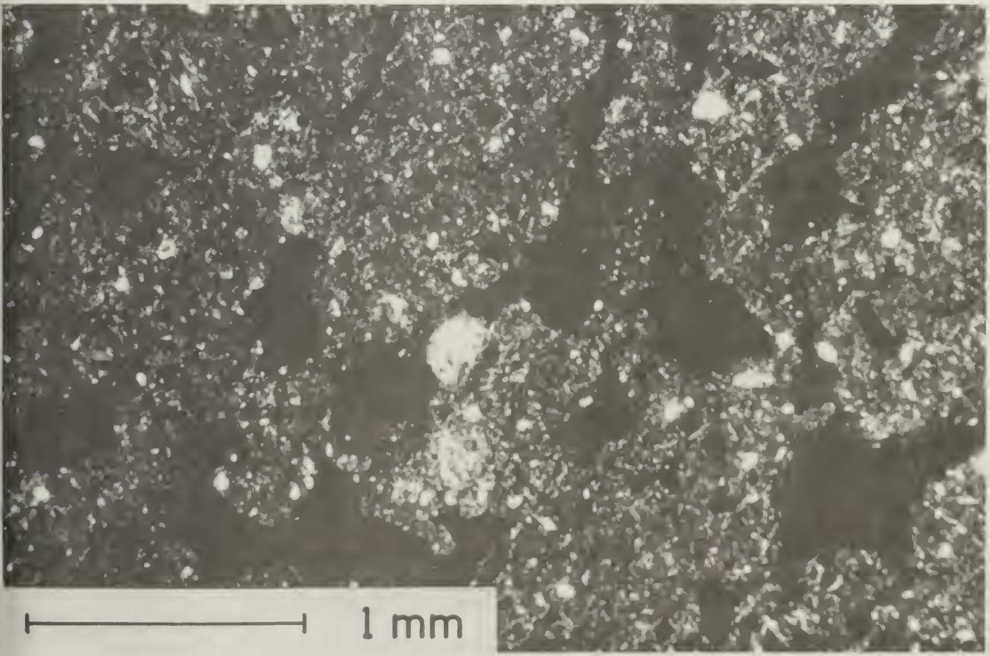


Fig. 7. Interconnected chambers built by an African termite species, as seen with a binocular microscope. Fig. 8. Mammilated metavughs formed by coalescing of inorganic pellets used for construction from an African termite mound (crossed nicols).

Fig. 9. SEM micrograph of a comb from the nest of an African termite (*Macrotermes michaelseni*). The comb appears to be constructed from plant fragments.

especially excrements are also subject to further microbial decomposition. The effect of specific soil animals on soil microflora (Arshad *et al.*, 1982) is becoming an important area for investigation. Fecal pellets are found with fungal hyphae, indicating their close association during decomposition of organic matter.

According to Geyger (1967), excrement together with organic residues are essential in the formation of soil structure, expecially in organic horizons depending on the decomposition stage of organic matter and the admixture of inorganic plasma and skeleton grains. Brewer and Pawluk (1975) have recognized certain types of granic and related fabrics, especially in the organic horizons of some Canadian soils. Their concept is strictly based on morphology; however, it can be related to soil genesis. It seems quite clear that more research is needed to understand the role of the fauna in the formation of soil fabrics.

Soil animals in organic horizons have a role in chemical decomposition and humification of plant residues and therefore accumulate nutrients in the biomass. Babel (1978) demonstrated that rate of fabric differentiation increased from the L to F and decreased in the H horizons, indicating the close positive relationship between humification and population of soil fauna. Despite research efforts in this area, details of these processes are still unknown.

In tropical countries, termites are capable of decomposing up to a third of the fresh annual grass, wood and leaf litter (Collins, 1981). This makes them the most important group of invertebrates in the decomposition of organic matter in their natural habitat. It is interesting to note that the fungi of the genus *Termitomyces* are the predominant microorganisms growing on the comb in certain termite nests. As can also be seen in Fig. 9, the comb is made up of mostly uningested plant materials (Rohrmann, 1978) and/or termite fecal pellets (Sand, 1960). Fungus cultivated on the comb was of nutritional value for the termites. This indicates a well-balanced cycle of organic matter in a harmony in which the termites have an important role.

INFLUENCE ON OTHER SOIL PROPERTIES

About 1.5 million kinds of animals are living on more than a million kinds (equivalent to the soil series, U.S. classification) of soils (Buol, *et al.* 1980). The action of soil fauna in combination with plants on initial parent material is prerequisite to soil formation.

Turbation of soils by animal activity (faunal pedoturbation) is generally well known to the pedologist (*e.g.*, Hoeksema, 1953; Slager, 1966). Krotovinas (Soil Survey Staff, 1951) are common features of Chernozem and dark colored soils commonly developed under prairie vegetation. They are the result of infillings of animal burrows by transportation of soil material from any direction. This contributes to the process of soil homogenization. Krotovinas appear in various sizes and are texturally and structurally unlike the surrounding soil materials. In semi-arid soils of Turkey, de Meester (1970) found that the contents of organic matter and nitrogen of krotovinas and the root development in krotovinas were considerably higher than the soil material of the horizon in which they existed.

Worm-worked soils are typical examples of how an animal group may significantly alter the soil characteristics. Such unique soil profiles were reported in several places in North America (*e.g.*, Buntley and Papendick, 1960; Nielsen and Hole, 1964; Wilde, 1971). Striking differences in macromorphological features and certain chemical characteristics are evident between the worm-worked profiles and the non-affected adjacent areas. Horizon boundaries within the turbation zone were obliterated. Buntley and Papendick (1960) clearly demonstrated that the B horizon which had high clay content originally was reduced in clay with the materials transported from both A and C horizons. As a result, the clay content of the A and C horizons were increased, whereas the B horizon was decreased. There was a distinct increase in organic matter and nitrogen content in the soils perforated with earthworms. Micropedological studies showed argillams of argillic horizons intensely reworked by faunal activities (Jongerius, 1962). We have observed similar effects in thin sections of some Kenyan Oxisols perforated by termites. Preferential selection of clay for mound construction by some termite species (Stoops, 1964; Lee and Wood, 1971) can cause a complete mixing of all horizons in Podzolic soils and soils with higher clay content in the subsoil than the topsoil.

It has long been recognized that the biological homogenization of soils is also of great importance in land reclamation from the sea sediments (Hoeksema, 1953; Slager, 1966). In the sediments of the famous Ijsselmeer polder, Bal (1982) observed that many channels which were formed by animals facilitated the deep rooting and consequently higher production of biomass.

Based on apparent lack of the original soil characteristics in worm-worked soils in South Dakota, Buntley and Papendick (1960) suggested that such soil be named "Vermisol". These soils display the features resulting from intensive perforation of worms. The humus type of forest soil mixed by earthworms is called a "Vermiol" (earthworm mull) by Wilde (1971). The recognition of such soils resulted in the establishment of the three great groups, namely, Vermiborolls, Vermudolls and Vermustolls in the Soil Taxonomy (Soil Survey Staff, 1975). These soils have a mollic epipedon that, below any Ap horizon, has 50% or more by volume of wormholes, wormcasts, krotovinas, or filled animal burrows of especially earthworms and their predators.

Because of the close relationship with soil organic matter, animals may play an important role in the reduction of water erosion. They create high water infiltration capacity as well as absorption due to production of organo-mineral complexes. In a detailed study, Arshad (1982) found that the soils influenced by termites were high in nutrients. This, together with favorable water availability and good drainage, resulted in a considerable increase in biomass in dry tropical parts of Kenya.

One has to be very careful in sampling, measuring and evaluating the effects of soil animals on soil properties. Micromorphometric measurements on samples reworked by animal activities (Mermut *et al.*, 1984) showed that in some parts of the biologically disturbed areas, porosity increased; however, compaction caused a considerable decrease in porosity in other parts. Apparently, improper sampling is one of the causes of controversy among scientists on the pattern of animal activity.

Among other influences, there is an increase of the availability of mineral nutrients and their distribution within the rooting zone. For example, earthworms increased the availability of N, Ca, Mg, K, P, and Mo (Nye, 1955) and Pb, Zn and Ca (Ireland, 1975).

CONCLUSIONS

Advances in soil micromorphology have made it possible to directly observe and study the influence of soil animals on soil characteristics and the role of the animals in soil genesis. Despite the studies and efforts of the past, our understanding of soil animals and their influence on soil microstructure is far from complete. There is need for more detailed studies dealing with micromorphological features and fabrics that are associated with special soil animals.

Soil fauna together with soil microorganisms have a very important role in accumulation, decomposition and redistribution of organic matter in the soil. Some animals in the tropics are capable of decomposing up to a third of the fresh annual grass, wood and leaf litter. Because of the close relationship with soil organic matter, animals may play an important role in increasing the aggregate stability and in reducing water erosion. They increase the availability of mineral nutrients within the rooting zone and they play an important role in land reclamation from sea sediments by homogenization.

Much knowledge on the effect of soil fauna on soil characteristics can be gained by experimental studies. Breakdown of litter, formation of biopores, perforation and behavior of each animal species can be determined in cultures under controlled laboratory conditions. With the help of micromorphological studies, details of the features produced by animals can be characterized. It is certain that without such experimental studies, present problems in micromorphological identification, quantification and description of faunal activity in soils will remain unsolved.

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